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THE DEVELOPMENT OF HIGH EFFICIENCY AIR CONDITIONER WITH TWO COMPRESSORS OF DIFFERENT CAPACITIES

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ABSTRACT

An air-conditioner driven by two compressors with different capacity was developed to improve energy efficiency by use high efficiency components and load matching. An algorithm for driving the two-compressor system was devised for optimum capacity modulation, and seasonal energy efficiency increased by 22%, when compared with that of a conventional air-conditioner of the same rated cooling capacity. If this achievement converted to electric power consumption, we confirmed that the monthly electric power consumption decreases 35% with the new system.

INTRODUCTION

The energy efficiency regulation of air-conditioner becomes tightened every year, because of the worldwide environmental protection movement. However, it became more difficult than ever, to reduce energy consumption without retail price increase. It is known that a variable speed compressor system shows higher efficiency, but the higher cost has not attracted consumers as many as the manufacturers expected. Therefore a new method was developed to improve the efficiency without adopting the expensive variable speed compressor.

There are two ways in indicating the energy efficiency, COP (Coefficient of Performance) and SEER (Seasonal Energy Efficiency Ratio). So far, the investigation for high efficiency was focused on the first method, but, in the view of saving the running cost during the cooling season, the second method which is represented by SEER can be more useful. The reason why the capacity modulation method is powerful to increase the energy efficiency of air-conditioning system is as follows. When measuring COP, the test unit operates at one rated test condition, but SEER considered entire cooling load conditions include the rated and minimum condition. In COP measuring system, there is an underlying assumption that the system with higher efficiency at one test condition would show higher efficiency at other operating conditions. But, this measurement omits the fact that the frequent cyclic start-and-stop operation of a compressor could lead to a sharp decrease in energy efficiency, which occurs at a minimum or low cooling loads. When the compressor stops, the high pressure refrigerant migrates into the low pressure side to level out the pressure difference.⁽¹⁾ When the compressor starts, it takes time to recover the high pressure, and it is one of the main reason for the energy loss in the constant capacity air-conditioner. When the cooling load is low, the variable capacity system slows down, and reduces the number of cyclic start and stop operation of the compressor, which saves lots of energy consumption.

Figure 1 lists several ways of capacity modulation. In this study, two-compressor system was selected based of

a previous research results in Kim et al ⁽²⁾. A capacity modulation system driven by two compressors was studied and its operating characteristics and energy saving effects were discussed.

EFFICIENCY IMPROVING TECHNIQUE

Synopsis

To increase the efficiency of air-conditioning system, it is necessary to improve the performance of compressor itself and design the heat exchanger efficiently to reduce the pressure gap between the condenser and evaporator. And another important thing is to develop the high efficiency components of system for reducing the power consumption. For example, we need to use high efficient circuit parts, which operate the compressor and the fan, and the chassis with less resistance and the fan with large air-flow. Also it is necessary to change the operation mode to minimum for preventing waste of electricity in case of light cooling load. Actually it means that, in the minimum operation mode, each components of the system also become high efficiency as they were at the rated operation mode. In this study, we tried to increase the efficiency by means of decreasing the power consumption. Using this concept, we can make the high-efficiency system not only in the minimum load but also in the rated load. With this system we saved a lot of electric power in summer season. The representative application technique is as follows; new cycle technique using a common accumulator, low vibration and resonance prevention design of pipe system, the optimum design of evaporator and condenser, the high efficiency motor (SRM: Synchronize Reluctance Motor) for indoor unit fan, a newly-developed outdoor axial fan, the optimized algorithm to control the degree of superheat and the room temperature, the minimization of a waiting electric power with SMPS (Switching Modulation Power Supply). With these techniques, we can save the power consumption by 35% compared with the existing model,. The typical specification and results are shown in Table 1.

New Cycle With A Common Accumulator

The schematic of system with a common accumulator and check valves is shown in Figure 2. Normally, in two compressors system, it is easy to occur the mal-distribution of the oil, and the reason is as follows. When the evaporated refrigerant flows into two compressors, the flow type of refrigerant is the annular flow. At this time, the vapor refrigerant and some oil which flow through the center of pipe can be distributed according to the capacity of compressors, but some of oil which flows on the wall of pipe is different in distribution effected by the shape and the mounted angle of the distributor and operation condition of compressor, so there will be the mal-distribution of oil in two compressor system. To overcome this effect, the common accumulator is newly developed as shown in Figure 3.

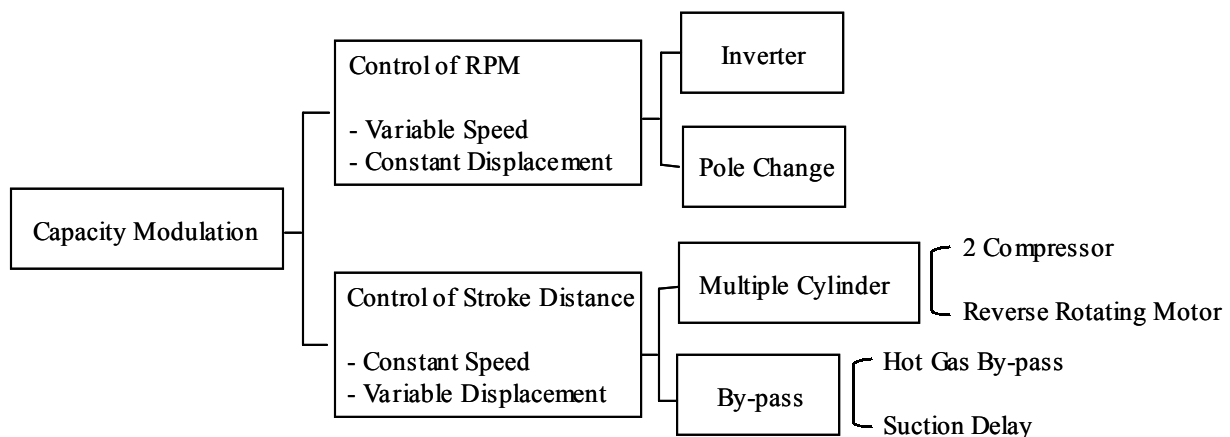


Figure 1: Classification of capacity modulation.

A refrigerant, evaporated in evaporator, flows into a common accumulator, and there the vapor refrigerant flows into each compressor through a suction line while the liquid refrigerant and oil are accumulated at the bottom of the accumulator. At this time, oil is recovered to the compressor through the oil-return hole with vapor refrigerant.

And in this system, check valves at the outlet of two compressors play important roles. During the minimum operation mode, it makes the stopped compressor as a receiver tank preventing the increase of the refrigerant charging amount. Its another role is to prevent the backflow of the refrigerant. Without check valve, partial refrigerant, compressed in driving compressor, flows into the stopped compressor and flows backward through suction pipe. It causes the decrease of mass flow rate, so the condensing pressure is increasing and the evaporating pressure is decreasing, finally the efficiency goes to bad. Of course, the check valves installed at the outlet of compressors would cause the a bad performance owing to pressure drop of vapor refrigerant, for that reason, the optimum design is necessary to minimize the pressure drop in system.

We can improve SEER by 3% with this check valves configuration to prevent the non-uniform recovery of oil and the backflow of refrigerant into the stopped compressor.

Low Vibration And Resonance Prevention Design of Tubing System

In this system, there are two rotary compressors that vibrate largely compared with scroll compressor, so it is important to prepare the injury of pipe system caused by the resonance. First, we choose several pipe system through the analysis of the natural frequency with FEM (Finite Element Method), the modal testing and examination of geometry. And then by the field tests for various condition such as a standard condition, overload condition, variable load and RPM of compressor, we modified the shape and the position of pipe system, decided the magnitude of additional mass for vibration deduction.

As a result, we can obtain small acceleration value, 1.3g which is enough to satisfy the regulation limit of our company, below 2g. The final shape of pipe system is shown in Figure 4 and the testing results are shown in Figure 5.

	Previous	Present
Compressor	1 Comp.	2 Comp.
Cooling capacity (W)	7,200	7,200/3,850 (Rated/Minimum)
SEER	3.20	3.91
Power consumption (kWh/month)	491	320
Running Cost (USD/month)	89.6	37.1
Size of Outdoor unit (W×H×D)	870×655×320	870×655×320

Table.1 The comparison of developed system

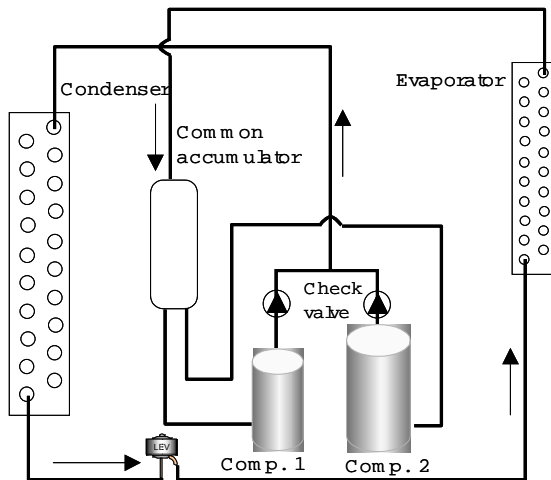


Figure 2 : Schematics of developed cycle.

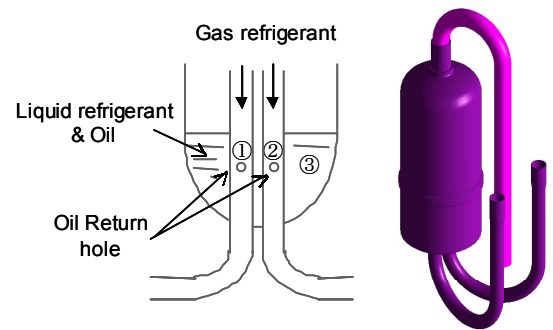


Figure 3 : A common accumulator.

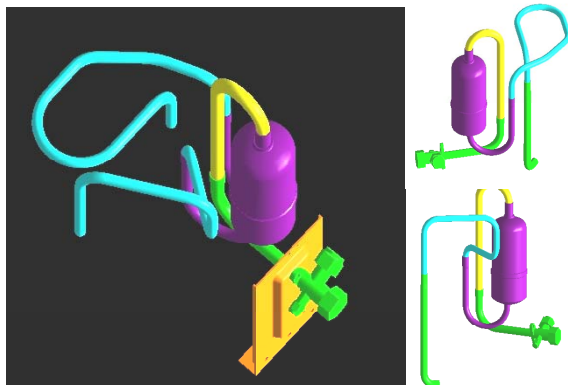


Figure 4 : Design of pipe system.

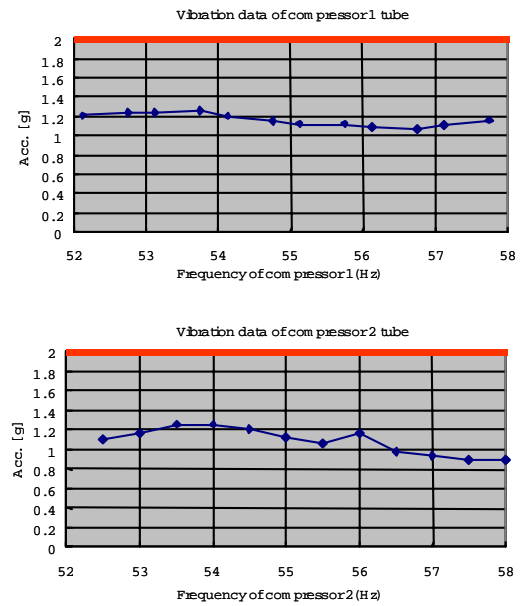


Figure 5 : Acceleration values of the connecting tube.

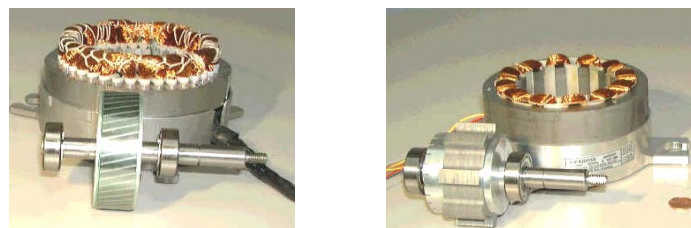


Figure 6 : Components of indoor unit fan motor.

Optimum Design of Evaporator

As an expansion device, we use EEV(Electronic Expansion Valve) instead of capillary tube. It can be more precision mass flow rate control of the system for wide range, but it is located in the outdoor unit. Therefore, it is necessary to optimize the refrigerant path in evaporator. We carried out both the computer analysis and experiments for the constant temperature distribution in each pass of evaporator. As a results, the cooling performance improved by 4% compared to the conventional one-compressor model.

High Efficiency SRM

The SRM (Switched Reluctance Motor) for indoor unit fan operates the rotator using the torque made by switching of phase. As a result, we can improve SEER by 3.4%. The real features of the original and the developed motor are shown in Figure 6.

Axial Fan of Outdoor Unit

The axial fan of outdoor unit spends a large part of the total electric power as 6~7%. The important design parameters of axial fan are pitch angle, the area of blade, sweep angle, and so on. In order to reduce the torque and the noise, we decrease the pitch angle, the area of blade and increase the sweep angle in equal rpm. So, we raised the rpm as much as the reduction of noise and moved the driving point of the motor.

As a result, we saved 30W in condition of the same noise and air-flow rate as those of the original fan. The original and the developed axial fan are shown in Figure 7.

Algorithm Optimization To Control The Degree of Superheat

It is important in cycle design to satisfy not only the efficiency but also the stability. Independent of the capacity variation and the combination of indoor/outdoor and desired temperature, the system operates stably when the degree of superheat which is the difference of temperature between the compressor inlet and the evaporator would maintains specific value. As stated above, we use electric expansion valve for expansion device that can control mass flow rate precisely, so we can improve the stability of system.

Moreover, we applied a proper control function, which is suitable to variable cycle characteristics and we can follow the changeable temperature condition like real situation. Figure 8 shows the experimental results for several control function to reach the target degree of superheat. In this figure, the third non-linear function represents excellent result. Specially, we choose another control algorithm for the first 90 seconds after operation to protect the compressor, Because a suction pressure can be decreased largely at the time of starting, so there could occur the liquid compression.

Indoor Air Temperature Control Algorithm

From the experimental results for preventing over-cooled condition, we developed the indoor air temperature control algorithm working without the hunting of temperature in case of repetitive on/off operation. We could reduce the operation cost by the maximum use of variable capacity modulation.

We apply the peculiar standard for judgment of the operating compressor by the indoor load and the average value of the accumulated operating time of compressor after starting. Figure 9 shows the result of the developed control algorithm. As the result of this, both power saving and comfort are realized.

SMPS

The efficiency of power supply unit was improved by way of changing the linear transformer, which supplies the alternating voltage to the micro processor, into SMPS(Switching Modulation Power Supply) and then we can minimize the power consumption to 0.4W level.

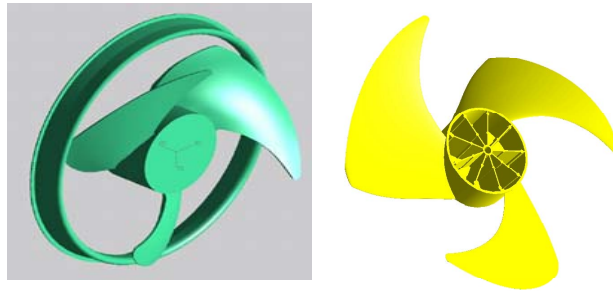


Figure 7 : Axial fan.

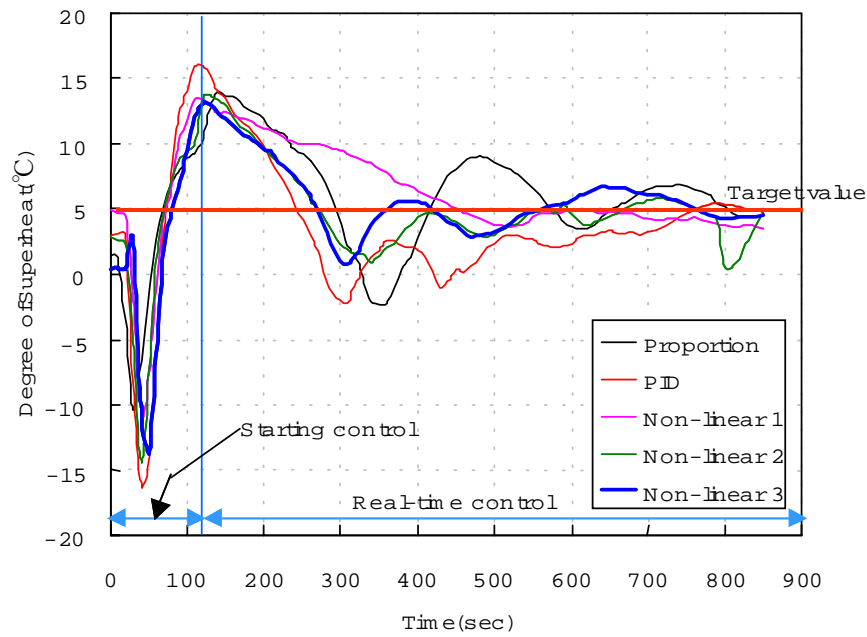


Figure 8 : Variation of control characteristics according to superheat control function.

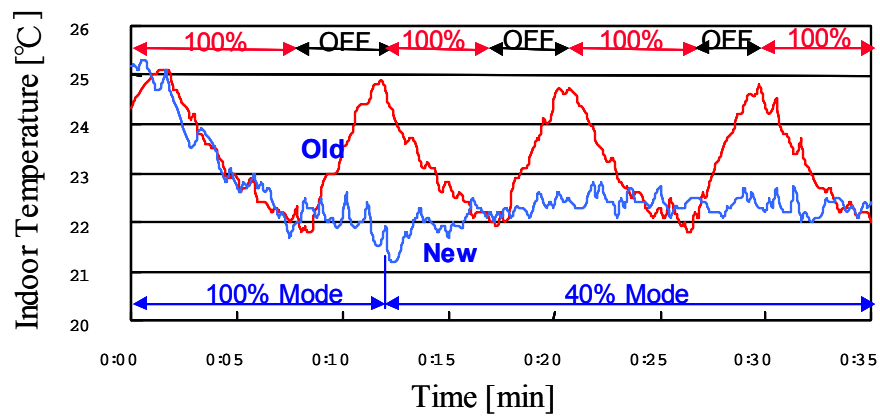


Fig.9 Comparison of indoor air temperature control algorithm.

RESULTS AND DISCUSSION

SEER

SEER (Seasonal Energy Efficiency Ratio) is used as a standard to define the annual power consumption of system. CSPF (Cooling Seasonal Performance Factor) is defined as follows for the capacity modulation system. [KS 9306(1999)]

$$CSPF = \frac{\sum Q_c}{\sum P_c}$$

$$\sum Q_c = \text{Total Cooling Capacity during Cooling Time}$$

$$\sum P_c = \text{Total Electric Power during Cooling Time}$$

In this study, when the outdoor temperature is above 34°C, the system operates continuously, because the rated cooling capacity is smaller than the building load. In case of outdoor temperature is below 33°C and the building load is between the rated cooling capacity and the minimum cooling capacity, the system operates in regular and minimum operation mode alternately. But, the building load is below the minimum cooling capacity, the system operates in minimum operation mode. The reason that the CSPF or SEER of capacity modulation system is higher than that of the previous one-compressor system is as follows. The power consumption is reduced when the number of repetitive on/off is decreased. Moreover, during the minimum operation mode, COP (Coefficient Of Performance, The relationship between the cooling capacity and power consumption) is improved as compared to the previous one-compressor system, because the decrement ratio of power consumption is more than that of cooling capacity. In the minimum operation mode, the capacity of condenser and evaporator is increased more than that of compressor as compared to regular operation mode. So, the difference between the condensing pressure and the evaporation pressure decreases, and as the results, the power consumption of the compressor decreases.

Descriptions	SEER
LP255CA	3.20
Two Comp. Drop in	2.877
Evaporator New Design	3.558
Dual Accumulator Two Valve Cycle	3.657
Outdoor Unit Air Flow Optimization	3.674
Indoor Unit Air Flow Optimization	3.692
Outdoor Unit Fan & Shroud Design	3.753
Indoor Unit Fan Optimization	3.775
SRM	3.913

Table.2 SEER enhance technology

Analysis of Contribution to SEER Improvement

Through this study, SEER of the previous one-compressor model is increased up to 3.91 (roughly 22% rise) and the electric power is saved by 35%. For the each technique mentioned before, the degree of contribution for total SEER improvement is calculated with simple SEER processing program and shown in Table 2.

CONCLUSIONS & FURTHER STUDIES

A new air-conditioner with two compressors, brand name “WHISEN”, was developed to reduce electric power consumption.

- (1) The monthly electricity consumption decreases 35% from 491 kWh to 320 kWh with the new system using the capacity modulation algorithm.
- (2) An oil recovery system was devised in which the two compressors share an accumulator in the air-conditioner, whereas a conventional system adopts an oil separator or an oil pressure equalizing pipe.
- (3) The improvement of SEER saves the running cost greatly in case the country like Korea have a progressive cost scale system for electricity.

We are planning to modify the two-compressor system and try to develop an advanced method for variable capacity modulation.

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